

Empirical analysis of gross vehicle weight and free flow speed and consideration on its relation with differential speed limit

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Each year the number of road accident fatalities and casualties are increasing and this cause a heavy burden on the health services and national economy. In Malaysia, for instance, the number of road accidents and fatalities are increasing every year and for the year 2008 the total accident increase by 2.7% and road fatality increase by 3.9% from the year before (according to Royal Malaysian Police). Based on accident data obtained from the Malaysian Institute of Road Safety Research (MIROS), the ratio of fatal accident involving heavy vehicle (FAIHV) to total road fatalities is relatively significant as in 2008 the ratio is 25.1%. This means that at least 25.1% of all road fatalities are due to fatal accidents involving heavy vehicles (because by definition a fatal accident is when at least one death occurs in that accident). An analysis of the accident fatality data further reveal that at least 41% of fatal accidents involving heavy vehicles occurred between the heavy vehicle and motorcycle.

Speed has been identified as one of the most important contributors to road traffic injuries. There are significant numbers of researches that have reported a strong statistical relationship between speed and road safety ([GRSP, 2008](#); [OECD/ECMT Report, 2006](#)). In addition, [Farmer et al. \(1999\)](#), [Clarke et al. \(2010\)](#) and [Dee and Sela \(2003\)](#) observed that speed not only makes a large contribution to all injuries but also the most important contributor to fatalities.

Among other risk factors, the need for regulating speed as a risk factor by introducing a speed limit is necessary in all highly motorized countries. Speed limits do influence the mean speed. However, the proportion of violations also changes with respect to the change in speed limit ([Elvik et al., 2004](#)). In addition to uniform speed limit (USL), where the same speed limit is applied for both passenger cars and heavy vehicle, differential speed limit (DSL) was introduced in many countries. Differential speed limits are speed limits that restrict all heavy vehicles, or at least heavy vehicles of a specific size, weight, or axle configuration, to traveling at lower speeds than the rest of the traffic stream ([Harwood et al., 2003](#)).

Analysis from first principles suggests that speed maybe an even more critical factor for heavy vehicle safety than for vehicles in general ([Brooks, 2002](#)). This is because, in contrast to passenger cars, heavy vehicles have more complicated systems with a variety

of possible failure modes and performance characteristics including locked-wheel braking, trailer swing-out, rollover, poor acceleration characteristics and longer braking distance. Furthermore, as mentioned by [Fancher and Campbell \(1995\)](#) the heavy vehicle weight shows the strongest association with fatal accident rates among all other vehicle characteristics such as wheelbase, configuration and number of axle. The finding is also consistent with physical principles that the energy to be dissipated in a collision is proportionate to weight. The kinetic energy to be absorbed equals one half mass multiplied by the square of velocity involved – expressing that during a crash, the amount of mechanical (kinetic) energy that must be absorbed by the impact is greater at a higher speed and mass. Further details about the energy loss in damage due to vehicles in road accidents can be found in [Vangi \(2009\)](#), [Wood and Simms \(2002\)](#) and [Wood \(1997\)](#).

In addition to the issue of accident potential, there are also other reasons for limiting the speed of vehicles with high GVWs, particularly the potential adverse effect high speeds of GVWs can have on road infrastructure and road maintenance costs. Road damage attributed to the effect of heavy commercial vehicles has been widely studied and documented ([Cebon, 1989, 1993](#)).

In Malaysia and some other countries, the speed limit for heavy vehicles are chosen to be lower than that of the passenger car and it is fixed for all types of heavy vehicles for simplicity and ease in regulation and enforcement.

Hence, although, there are many factors that can be associated with accident crashes, this study focuses on the speed of vehicles and attempts to explore empirically the relationship between the free flow speed and gross vehicle weight (GVW) especially heavy vehicle. Based on this analysis, a new concept of determining speed limit for heavy vehicle incorporating GVW is proposed.

Approach

Data collection

Data were collected from continuously operated weigh-in-motion (WIM) station that works in all weather conditions, 24 h a day and 7 days a week throughout the year. The system is located on a rural single carriage-way two-lane road with straight and flat road geometry, named Federal Route 54. The basic configuration of the developed WIM system installed at the study location is shown in [Fig. 1](#). It uses the quartz piezoelectric sensor as the main sensory device to capture traffic and vehicular data. The WIM system was installed over the one lane section to capture all traffic in the westward direction. After installation, the WIM system was calibrated and validated to ensure that all traffic and vehicular data

were within the Type 1 performance specifications specified by ASTM Standard E 1318-02 (ASTM Standard, 2002).

Traffic data obtained through the WIM system include traffic flow, classified count, average daily traffic (ADT), vehicle headway, vehicle speed, time gap, and vehicle acceleration or deceleration. As for vehicular data obtained through the WIM system it includes vehicle type, axle spacing, number of axles, gross vehicle weight and axle load.

For the purpose of this study, in order to remove the influence of the surroundings and the behavior of other drivers, data were selected based on following conditions:

- Dry weather condition
- No change in the infrastructure and surrounding
- Vehicle speed more than 40 km/h
- Time headway more than 5 s.

Data analysis

The statistical analysis is categorized into two parts: (1) twoway ANOVA analysis to explore how both vehicle class and GVW effect on speed and their interaction effect, and (2) 85th percentile speed distribution analysis for finding the most appropriate speed limit when GVW is incorporated. For both cases, the speed data are grouped according to vehicle class and GVW range. In this study, according to Malaysian Road Transport Department, the heavy vehicle is classified based on their number of axle configuration.

Results

To explore the relationship among speed, class and GVW, the matrix scatter plot is plotted as shown in Fig. 2. It can be clearly seen that the variation of speed data for every vehicle class and GVW range is considerable and the variation is decreasing as the number of axle or GVW increases. The figure also shows that the relationship between class and GVW where the same type of vehicle can have variation of GVW especially for 3-axle until 6-axle truck. To investigate whether the effect is statistically significant, two-way ANOVA analysis was carried out.

Table 1 shows that overall there was significant effect of both class and GVW on speed, $F(9, 7608) = 16.16$, $p < 0.01$ and $F(5, 7608) = 29.16$, $p < 0.01$.

Fig. 3 shows that when GVW is ignored, the mean speed is very similar among 3-axle ($M = 57.58$, $SD = 7.38$), 4-axle ($M = 58.09$, $SD = 7.14$), 5-axle ($M = 59.68$, $SD = 7.80$), and 6-axle ($M = 57.98$, $SD = 7.15$) vehicle class. However, the significant main effect of class can be seen as the increase in the mean speed for passenger car

($M = 75.06, SD = 12.14$), and 2-axle truck ($M = 63.58, SD = 10.64$). This finding seems to indicate that the vehicle category did affect the speed but not among more than 3-axle heavy vehicles

Considering GVW, the results from the analysis also indicate that when vehicle class is ignored, the average speed of GVW range more than 20 t was fairly similar while for GVW range less than 20 t, the mean speed is significantly different. The meaning of this main effect can be seen in the error bar chart as shown in Fig. 4 and the R-E-G-W-Q test as given in Table 2 confirms the earlier statement.

The two-way ANOVA results in Table 1 also indicate that there was a significant interaction between the class and GVW, on travel speed, $F(28, 7608) = 7.39, p < 0.01$. The important point now is how the effect of GVW on speed is different for each category of vehicle since there is a large variation of GVW for each vehicle category as shown by the matrix scatter plot in Fig. 2. This also reveals that the result demonstrated earlier for 3-axle to 6-axle truck (the class main effect) in which there was no significant difference in mean speed is misleading if this interaction or GVW is not taken into consideration.

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